Transient processes in the sections of the long lines

F. F. Mende

http://fmnauka.narod.ru/works.html mende_fedor@mail.ru

The article describes the transients in segments of long lines.

Faradey established the law of induction, carrying out experiments on the solenoids, including turning off in them current, or moving with respect to the solenoids the turns of the wire, to which was connected the galvanometer. Its point of view, which is considered accurate and today, was reduced to the fact that with the connection to the solenoid of the dc power supply U, then current in all its turns increases according to the linear law of

$$I = \frac{Ut}{L}, \qquad (1)$$

where L - inductance of solenoid.

Consequently, magnetic field with this interpretation for entire elongation of solenoid will increase synchronous. However, so whether this in reality? In order to understand, so this, let us examine a question about how swelling current in the shortened out section of long line will.

If we the line, depicted short out at a distance z_1 of beginning, i.e. summary inductance will compose the value $L_\Sigma = z_1 L_0 = z_1 \frac{a}{b} \mu_0$. If we connect to the line dc power supply, in it will begin to be extended the wave of the voltage U and current $I = \frac{U}{Z}$ as shown in Fig. 1 . The wave of stress in its right part has the transition section z_2, which is named the front of the wave of stress. This section corresponds to the transit time $\tau = \frac{z_2}{c}$, for which the voltage of the source, connected to the line, attains its nominal value.

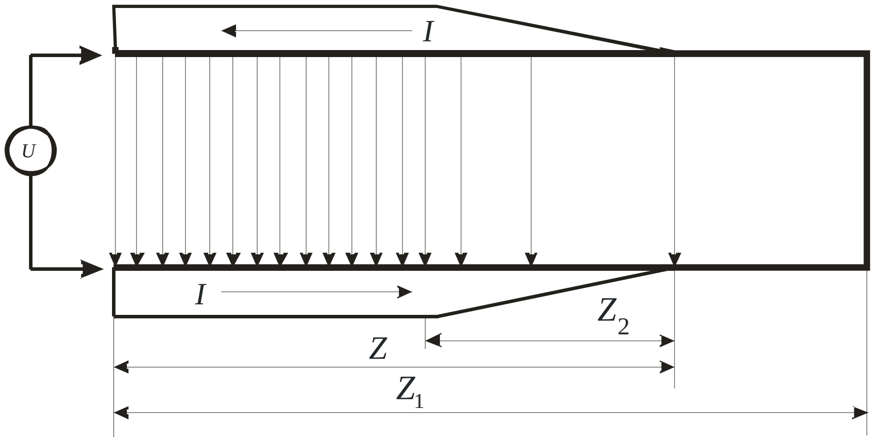

Fig. 1 . Propagation of the current wave and voltage in the long line.

Simultaneously with the wave of stress in the line will move current wave. Specifically, in this transition section proceeds the acceleration of the charges from the zero speed in its beginning, to the values necessary for creating the rated current in the line, whose value is determined by the relationship $I = \frac{U}{Z}$. To this section is applied the voltage of the power source. In this case it is accepted that during the voltage transient increases according to the linear law. It is accepted also that the time of this transient process is considerably less than the time, for which the front of stress passes along the line to one side. It is assumed that z_1 is considerably greater than z_2. At the moment of the time, when on the cross connection in the end of the line appears the front of the stress of appears the wave with the stress of reflected, which runs in the opposite direction. Since current in the wave reflected is equal to stress with the negative sign and it moves in the opposite direction, then the summed current, created by this wave will be equal $-\left(-\dfrac{U}{Z}\right)=\dfrac{U}{Z}$, i.e., it there will be leak in the same direction as the current of the incident wave. Thus, the wave reflected, moving in the opposite direction, will leave after itself current, equal $\dfrac{2U}{Z}$, and zero voltage. When the front of stress to return at the beginning to line, it brings with itself the state of the doubled initial current and zero voltage. Source will again send into the front line of the stress U and current $\dfrac{U}{Z}$. This current will be formed with the current $\dfrac{2U}{Z}$, and summed current in the line will compose $\dfrac{3U}{Z}$. Current will further increase by steps, adding each sequential time to its previous value the value $\dfrac{2U}{Z}$. This process is depicted in Fig. 2. In this figure the time

$$T=\frac{z_1}{c}=z_1\sqrt{L_0C_0}=z_1\sqrt{\mu_0\varepsilon_0}$$

it is equal to the time, for which the front of stress passes along the line to one side of beginning to the shortened out section.

The special feature of this process is that that the selection of energy from the voltage source will not be subordinated to linear law, but it will have spasmodic nature. The power, selected in the range of time from zero to $2T$, will be equal $\dfrac{U^2}{Z}$. But in each subsequent interval of the time, equal $2T$, it will grow already to the value $\dfrac{2U^2}{Z}$. Thus, the growth of current bears completely not linear, but spasmodic nature. The process indicated occurs with any length of line. With the small length of gallop they follow through the small time intervals and the dependence of current on the time approximately it is possible to consider it linear that also is characteristic for the elements with the lumped parameters.

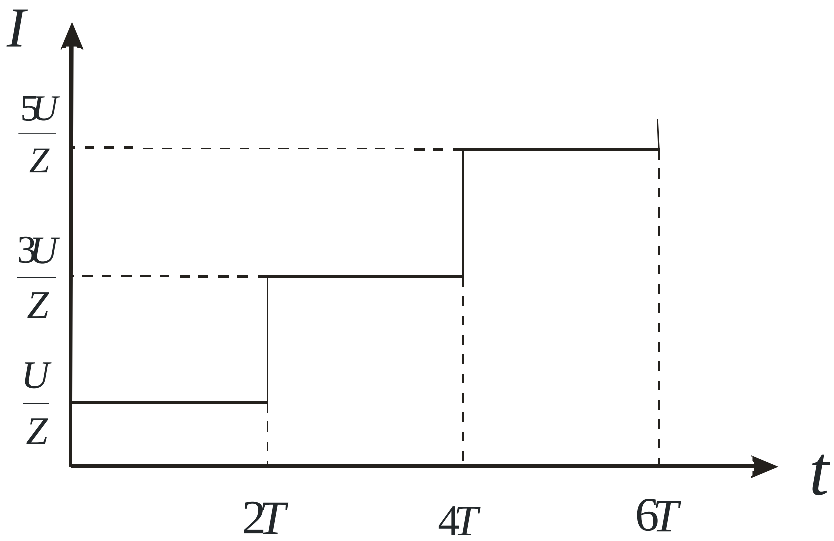

Fig. 2. Dependences of input current on the time for the shortened transmission line.

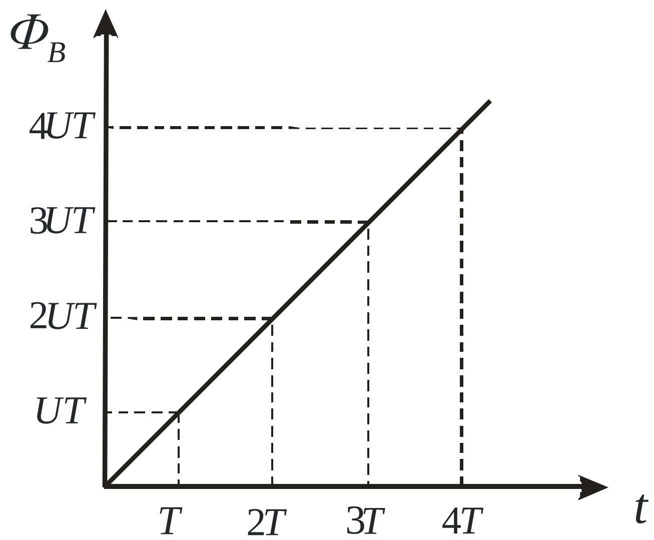

Fig. 3. Dependence of magnetic flux on the time for the shortened transmission line.

should be focused attention on the fact that, the power, selected by the shortened out line in the source of voltage (Fig. 2), it is not linear function, but after the time equal $2T$ abruptly it increases by $\frac{2U^2}{Z}$, the first of gallops corresponding to the selected power $\frac{U^2}{Z}$.

Is not difficult to show that the magnetic flux in this case changes according to the linear law (Fig. 3). Actually, during the forward stroke, to the moment of reaching by the wave of the shortened out section, flow will increase in the linear law, and up to the moment T it will reach the value

$$\Phi_B = \frac{z_1}{c}U .$$

When, after being reflected from the shortened out section, the front of stress will begin to move in the opposite direction, then flow will continue to grow according to the linear law, and up to the moment of the arrival of the front of stress at the voltage source it will conversely reach the value

$$\Phi_B = \frac{2z_1}{c}U .$$

Thus, with the connection of the shortened out line to the voltage source is carried out the law of induction $U = \frac{d\Phi_B}{dt}$.

The electric flux in the line will also change, but according to another law (Fig. 4)

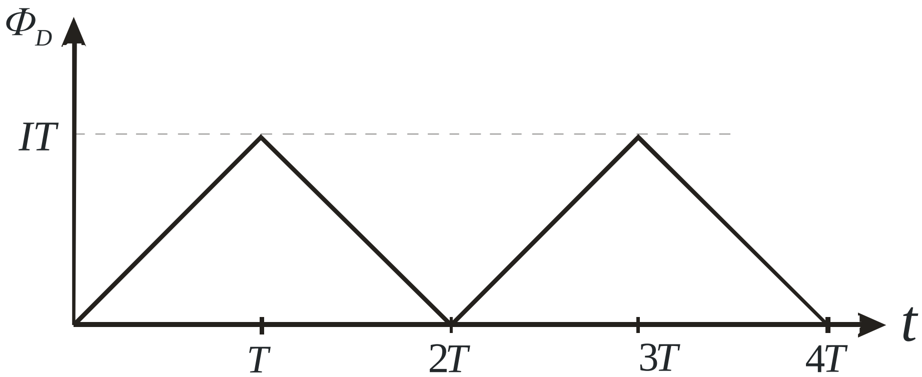

Fig. 4. Dependence of the electric flux on the time for the shortened transmission line.

In contrast to the magnetic flux it will change periodically, first, growing, then, diminishing, according to the linear law. When wave moves in the positive direction, simultaneously grows magnetic and electric flux. In this case, both in the magnetic and in the electric field stored energy grows. When wave begins to move in the opposite direction, then electric field begins to disappear, and its energy passes into the magnetic energy of reverse current wave. After the front of the wave of stress reaches incoming line, magnetic field and current in it doubles, and electric field disappears. Further cycle is repeated. Consequently, the process of the growth of magnetic flux in that shortened outed by long line, in the required order accompanies the process of an alternation in the flow of electrical induction, as a result of which between the planes of line periodically it appears and it disappears electric field.

Let us assume that line is made from superconductor and loss-free. Then after replacing at the specific moment the voltage generator with the superconductive cross connection, it is possible to freeze current in the line. The moment, when in the line electric field completely is absent is favorable moment for this procedure. Then in the line is frozen the flow $\Phi_B = \frac{2Nz_1}{c}U$, to which will correspond the current $I = \frac{2NU}{Z}$. What will be, if the voltage source by the superconductive cross connection was replaced at that moment of the time, when in the line is found the front of stress and what- t. e section it is filled with electric fields? In this case this section will move in the line, being alternately reflected thus one, thus another end of the shortened out line, until it spends its energy for the emission. Only integral (quantized) value of flow and current in accordance with the given relationships can be frozen for this reason in the line shortened out from both sides.

This phenomenon is an example of the macroscopic quantization of flow in the macroscopic structures, which have the specific sizes. The same quantization of flow occurs also in the microscopic structures, which the atoms are.

From the point of view of chains with the lumped parameters, growth of current in the solenoid with the connection to it of the voltage source occur according to the linear law, moreover in all its turns simultaneously. But so whether this? For explaining this question let us replace the upper plane of the two-wire circuit (Fig. 5) by long solenoid. If we to this line connect the voltage source, then the process of the growth of current in it will in no way differ from that examined. The linear inductance of line will be now in essence determined by the linear inductance of solenoid and the velocity of propagation and current wave, and the wave of the stress (stress now it will be applied between the solenoid and the lower conductor of line) it will be less than in the preceding case.

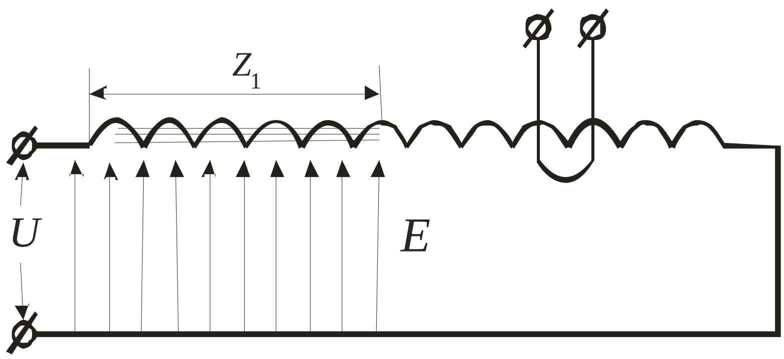

Fig. 5. The diagram of the propagation of magnetic and electrical pour on in the long solenoid.

When in the line examined wave will reach the point with the coordinate z_1, then magnetic field fill only the part of the solenoid, located between the power source and the point z_1. When wave reaches its end, then magnetic field fill entire solenoid. The magnetic field in the solenoid will be doubled with the back stroke of wave, and process will begin first.

Let us place now that the solenoid in the specific place is envelopped by turn. This process is such to mechanical dressing of the covering turn to the end of the solenoid with the only difference that in this case magnetic flux, being moved inside the solenoid, itself it pierces its covering turn. Moreover the speed of the motion of the front of magnetic flux in this case is incommensurably more than during mechanical dressing. But both processes have identical nature. By these processes is explained the phenomenon of the mutual induction between the solenoid and the covering turn. The pulse separation is small with the small length of solenoid; therefore they, merging, is formed almost constant stress. Stress in the turn will be induced only at the moment of the intersection with the magnetic flux of the solenoid of the environments of the cross section, envelopped by turn. In the environments of the covering turn will at this moment appear both the vector potential and the magnetic field. And, precisely, the intersection of the covering turn with the magnetic fields of the scattering (the same, as at the end of the solenoid with the direct current) leads to the induction in it emf. This moment will begin both with the straight line and with the back stroke of wave; moreover the polarity of the voltage pulses, induced in the turn, in both cases will be one and the same. The frequency of these pulses will depend on the length of solenoid, and it will be the greater, the shorter the solenoid. Consequently, the average value of the induced stress will be grow with the decrease of the length of solenoid, i.e., its quantity of turns, that also determines the transformation ratio of this transformer. This coefficient is equal to the relation of a quantity of turns of solenoid and ironclad.

After examining the process of the growth of currents pour on in the long solenoid, let us return to the problem of the presence of the circulation of vector potential around the long solenoid. Let us give the existing point of view on this question, represented in the work [1]. The value of vector potential in the space, which surrounds solenoid, is found from the relationship

$$A(r) = \frac{nIr_0^{\,2}}{2\varepsilon_0 c^2 r} \tag{2}$$

where n - quantity of turns, which falls per unit of the length of solenoid, I - the current, which flows through the solenoid, r_0 - diameter of solenoid, r - distance from the axis of solenoid to the observation point. It is assumed during the record of this relationship that $r \geq r_0$.

The inductance of solenoid is determined by the expression

$$L = \frac{n^2 \pi r_0^{\,2} z_0}{\varepsilon_0 c^2}, \tag{3}$$

where z_0 - length of solenoid.

If we to the solenoid connect the dc power supply U, then taking into account relationships (1 - 3), we obtain

$$A(r,t) = \frac{Ut}{2\pi N r},$$

where N - total number of turns in the solenoid, and since

$$E = -\mu_0 \frac{\partial A}{\partial t},$$

that the tension of electric field in the environment of solenoid at the moment of the connection to it of dc power supply will comprise

$$E(r) = \frac{\mu_0 U}{2\pi N r}.$$

The tension of electric field in accordance with the version in question appears at the moment of connection to the solenoid of the power source instantly for entire its elongation. If the solenoid lacks resistance, then the tension of electric field will be constant during entire period of the time of connection to the solenoid of dc power supply. What here do appear contradictions? First, electric fields possess energy, and instantly they cannot appear. The second contradiction escapes from the first and consists in the fact that, since the electric fields possess energy, this energy must be included in the general energy, accumulated in the solenoid. But only magnetic fields inside the solenoid are considered with the calculation of this energy.

Thus, very process of inducting the electrical pour on around the long solenoid it occurs in no way in the manner that this represented in the existing literature [1], when it is considered that the circulation of magnetic vector potential for entire its elongation grows simultaneously, that also leads to the induction electromotive force (EMF) in the covering turn.

From the aforesaid it is possible to conclude that the point of view about the appearance of electrical pour on inductions around the solenoid in that place, where the rotor of vector potential is equal to zero, it does not correspond to reality, and very process of the formation of vector potential outside the solenoid and magnetic pour on inside it it does not correspond to those ideas, which exist today. The rotor of vector potential outside the solenoid is equal to zero, and this field possesses no energy; therefore to reveal it in the static behavior is impossible. For this reason the Aronov and

Bohm experiments for the detection of vector potential outside the long solenoid, as which was used the magnetized ferromagnetic cylindrical model of small diameter, should be considered erroneous.

Литература.

[1] Фейнман Р., Лейтон Р., Сэндс М. Фейнмановские лекции по физике. М: Мир, 1977.